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RESEARCH PAPER

Seasonal changes of bioelements in litter and their potential return to green leaves in five species of tropical dry deciduous forest, western India

J. I. Nirmal Kumar • Rita N Kumar • Rohit Kumar Bhoi • Kanti Patel

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Abstract: The Litter nutrient concentrations of N, P, Ca, Mg, K and Na in mature leaves, twigs and reproductive parts and their relationship between senescent and young leaves were investigated in five forest species: *Acacia nilotica*, *Acacia leucophloea*. *Tectona grandis*, *Miliusa tomentosa* and *Butea monosperma* in Indian tropical dry deciduous forest in Western India.. Total dry matter of plant species was recorded and analyzed for N, P, Ca, Mg, K and Na. *A. nilotica* had the highest concentrations of N in leaf, while *A. leucophloea* had the highest concentrations of Ca and Mg in leaf. The highest concentrations of P in leaf were found in *A. nilotica*, *A. leucophloea* and *B. monosp*erma where as lowest in *T. grandis* and *M. tomentosa.* No significant differences in K and Na were registered among the species. A marked seasonal variability was observed in the concentrations of N, P and K, except for Ca and Mg. Potassium is the single element that undergoes leaching and mobilization in all species. Resorped N and P can be used for the production of fresh leaf in the following annual cycle. Nutrient resorption and retranslocation from senescent leaves and litter supports the production of new foliage and increase the fertility of soil.

Keywords: Tropical dry deciduous forest; nutrient concentration; senescent and fresh leaves; nutrient return; nutrient resorption efficiency

Introduction

Nutrient resorption allows leaf bioelements to be reused rather than lost with leaf fall, thus extending the mean residence time of bioelements in plant. Retranslocation of bioelements from senescent leaves of trees to perennial organs is a common phenomenon in forest ecosystems (Wright et al. 2003). In some studies, retranslocation was observed to increase with increasing nutrient limitation (Craine et al. 1998). Retranslocated N and P could satisfy the demand of these elements for the production of new leaves (Sundarapandian et al. 1999). Such resorption, which results in reduced cycling by the litter, allows the ecosystem to become largely independent of the soil substrate (Yan et al. 2006).

The resorption of bioelements prior to leaf fall is one of the key processes to conserve nutrient by plants. This process reduces the likelihood of nutrient loss in litter dropped on the forest floor (Van Heerwaarden et al. 2003) and subsequently, the withdrawn bioelements are redeployed in new tissues, such as leaves and reproductive structures or stored for later use (Vitousek et al. 1994). There is substantial evidence that trees can reduce nutrient loss during leaf fall through withdrawal of nutrients from senescing leaves before abscission (Ostman et al. 1982). The evidence for nutrient resorption from tree leaves is suggested by a decrease in absolute amounts of N, P, and K in leaves during senescence (Woodwell 1974). Measurements of resorption rely on the assumption that all nutrients lost from the leaves are resorped, or leached by rain and appear through fall (Eaton et al. 1973). Few studies reported the retranslocation and resorption efficiencies in tropical forest ecosystems (Aerts 1996; Cuevas et al. 1998; Kathryn et al. 2000); however, there is a lack of knowledge concerning the seasonal changes of bioelements in the litter and their potential return to fresh leaves in five species of the Indian tropical dry deciduous forest of Western India. The main objective of the present study was to evaluate: (1) the seasonality of nutrient concentration of litter leaves, twigs and reproductive parts and; (2) the elements N, P, Ca, Mg, K and Na relationships of senescent and fresh leaves in five forest species; (3) to determine the percentage of nutrient resorption efficiency and percentage of nutrient retranslocation in five forest species.

Materials and methods

Study area

The study was conducted in southern part of Rajasthan in the

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J. I. Nirmal Kumar (✉) • Rohit Kumar Bhoi • Kanti Patel
Post Graduate Department of Environmental Science and Technology, Institute of Science and Technology for Advanced Studies and Research (ISTAR), Vallabh Vidyanagar, 388 120, Gujarat, India
Email: istares2005@yahoo.com; isaiah_nir@yahoo.com

Rita N Kumar
Department of Bioscience and Environmental Science, N.V. Patel college of Pure and Applied Sciences, Vallabh Vidyanagar - 388 120, Gujarat, India

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Aravally mountain region (23°3' N latitude and 69°30' E longitude; altitude 579.4 m above the mean sea level). The climate of this region is sub-tropical to monsoonal with three distinct seasons. The summer season is from March to June, the rainy season from July to October, and the dry cold winter season from November to February. The mean minimum temperature ranges from 2.5°C to 26.8°C and mean maximum varied from 28.8°C to 45.3°C. The average rainfall of the area is 492.65 mm, of which about 90% occurs in four months of the year from June to September. The soil is alluvial, yellowish brown to deep medium black and loamy with rocky beds.

Experimental design

Five plots (each plot is 100 m ×100 m) were selected to represent sites of relatively uniform soil and vegetation in each plot; five individual trees of each of the five dominant species in this forest were selected. The following tree species are chosen because they are native and for the value of their wood: (1) *Acacia nilotica*, family: Mimosaceae, tree with 5−6 m tall and diameter at breast height (DBH) of 11−13 cm; (2) *Acacia leucophloea*, family: Mimosaceae, tree with 4−5 m tall and DBH 11−12 cm; (3) *Tectona grandis*, family: Verbenaceae, tree with 5−6 m tall and DBH 13−14 cm; (4) *Miliusa tomentosa*, family: Annonaceae, tree with 5−6 m tall and DBH 15−17cm; (5) *Butea monosperma*, family: Fabaceae, tree with 5−6 m tall and DBH 10−12 cm.

Five square litter traps (1 m×1 m each) were randomly kept under each selected tree at 0.5 m above the ground. The litter from each trap was collected at monthly intervals (August 2007-July 2008), placed in labeled polyethylene bags and brought to the laboratory and then sorted into leaves, twigs and reproductive parts then dried at 70°C in a oven until constant weight was reached. The weight of each fraction was recorded, and its percentage of the total litter was calculated. Green leaves were sampled from lower and upper, middle and outer canopy and then pooled for each tree species. Senescent leaves of five deciduous tree species were obtained by shaking the branches. During the period of maximum leaf shedding (November to February), the resorption index of each nutrient was calculated as the difference between the nutrient concentrations in senescent leaves and green leaves expressed as a percentage of the green leaf concentration (Ralhan et al. 1987).

Analytical determinations

Green (fully developed, healthy and remaining green leaves) and senescent leaves (yellow but still attached to the plants) were collected from each species during different seasons, which were rinsed with distilled water and then oven dried at 70ºC to a constant weight and ground separately and passed through 0.5-mm sieve. The sample determinations were prepared by wet digestion using perchloric and nitric acid (1:5, v/v) for nutrient concentration. After digestion, concentrations from total N, P, Ca, Mg, K and Na were determined; Nitrogen was determined by micro-Kjeldahl technique; Phosphorus was determined by phosphomolybdic blue colorimetric method. Calcium and magnesium were determined by EDTA titration method and potassium and sodium were determined by flame photometry, followed by standard Research methods of Plant analysis (Narwal et al. 2007).

Computations and statistics

Percentage of resorption was calculated on the basis of content using the mean values of fresh and senescent leaves for each species using the following equation (Fahey et al. 1991).

$$R_e\,(\%) = 100\,(N_u - N_c)/N_s \tag{1}$$

where, R_e is the resorbtion(%), N_u is the nutrient concentration of fresh leaves, N_c the nutrient concentration of senescent leaves, and N_s the nutrient concentration of fresh leaves.

The percentage nutrient retranslocation (R) was calculated according to Lodhiyal et al. (2002):

$$R\ (\%) = \frac{X - Y}{X} \times 100 \tag{2}$$

where, X is the nutrient content in green leaves, and Y the nutrient content in leaf litter. For analysis of variance, all variables were assessed for normally using probability plots. Homogeneity of variance was tested using Bartlett's procedure.

Results and discussion

Litter production

Table 1 shows that highest amount of litter biomass was collected in traps located under trees of *T. grandis*, followed by *B. monosperma*, *M. tomentosa*, *A. leucophloea* and *A. nilotica*. The foliage litter was the most relevant in quantitative terms followed by twigs and reproductive parts. In July-September, many twigs and reproductive parts were shed due to heavy rainfall, whereas in the cold month (October -February) there was a greater contribution of foliage litter. *T. grandis* contributed significantly (p<0.01) greater amounts of leaf, twigs and reproductive litter to the total annual litter fall, followed by *B. monosperma*, *M. tomentosa*, *A. leucophloea* and *A. nilotica*.

Nutrient concentrations in green and senescent leaves

The nutrient concentrations in green leaves were strongly correlated with those in senescent leave, which differed within and among the tree species (Table 2). The nutrient concentrations observed in the present deciduous trees species (*A. nilotica*, *A. leucophloea*, *T. grandis*, *M. tomentosa* and *B. monosperma*) were higher than those reported for Eucalyptus plantation (Bargaly et al. 1992) and Shisham forest (Lodhiyal et al. 2002). The contents of N and P were significantly reduced in senescent leaves whereas Ca, Mg, K and Na contents increased in senescent leaves in all species such as *A. nilotica*, followed by *A. leucophloea*, *T. grandis*, *B. monosperma* and *M. tomentosa*. The N, P,

Ca, Mg, K and Na contents varied form one species to another and there is significant difference (p<0.05) between species in nutrient concentrations. In present study, all bioelements values were within the range values reported from other tropical forests (Kappelle et al. 1996).

Table 1. Total dry weights and percentage of the different fractions of collected litter ($kg\cdot ha^{-1}\cdot a^{-1}$)

Species	Leaves			Twigs			Reproductive parts			Total dry matter	
	Dry weight	s.d.	Percentage	Dry weight	s.d.	Percentage	Dry weight	s.d.	Percentage	Dry weight	s.d.
Acacia nilotica	628^{a}	101	65.0	162^{a}	21	25.7	75^{a}	34	9.3	865^{a}	156
Acacia leucophloea	707^{b}	64	66.9	185^{b}	27	24.8	88^{b}	29	8.3	980^{b}	120
Tectona grandis	5151^{a}	381	65.8	1347^{a}	373	26.0	346^{a}	138	8.2	6844^{a}	892
Miliusa tomentosa	4064^{a}	361	62.4	995^{a}	340	29.1	252^{a}	140	8.5	5311^{a}	841
Butea monosperma	4283^{b}	528	64.4	1030^{b}	348	27.5	284^{b}	131	8.0	5597^{b}	1007

Notes: Different superscripts indicate significant differences (a=P<0.01, b=P<0.001) between species in weight of each fraction (n =15).

Seasonal variation in nutrient concentrations of the litter components

The seasonal variation in the nutrient concentrations of leaves, twigs and reproductive parts for the species, *A. nilotica*, *A. leucophloea*, *T. grandis*, *M. tomentosa* and *B. monosperma* are presented in Fig. 1. The concentration of N and P in the leaves of each species varied throughout the year, the highest nutrient concentration in levels being recorded in monsoon and the lowest in winter (Fig. 1 A, B). The concentrations of these two bioelements in the litter are considered to be critical for decomposition (Sundarapandian et al. 1999). The concentration of Ca and Mg showed a similar seasonal trend for all species studied (Fig.1 C, D). The highest concentrations of K and Na were found in winter and lowest in summer (Fig. 1 E, F). The concentration of K and Na were higher during winter and was probably related to the loss of weight of senescent leaves (Alley et al. 1998). All the bioelements in the branches and fruits of the species studied showed annual distribution patterns are similar to those of the leaves. The concentrations of N and P were significantly lower in twigs and reproductive parts, as previously reported in the literature (Leonardi et al. 1997). The nutrient concentration of the reproductive parts of litter fraction did not vary significantly throughout the year.

Table 2. Nutrient concentrations in fresh and senescent leaves of forest species ($g\cdot kg^{-1}$)

Bioelements	*Acacia nilotica*		*Acacia leucophloea*		*Tectona grandis*		*Miliusa tomentosa*		*Butea monosperma*	
	GL	SL	GL	SL	GL	SL	GL	SL	GL	SL
N	$19.20^{*a}\pm1.23$	$17.8^{*a}\pm1.69$	$18.43^{a}\pm0.16$	$16.91^{a}\pm0.8$	$17.43^{b}\pm0.56$	$16.30^{b}\pm0.7$	$16.13^{a}\pm0.45$	$13.80^{a}\pm0.6$	$18.27^{c}\pm0.34$	$15.50^{c}\pm0.4$
P	$0.99^{a}\pm0.08$	$0.91^{a}\pm0.08$	$0.86^{b}\pm0.06$	$0.79^{b}\pm0.06$	$0.79^{b}\pm0.08$	$0.72^{b}\pm0.08$	$0.65^{a}\pm0.05$	$0.59^{a}\pm0.05$	$0.78^{b}\pm0.04$	$0.74^{b}\pm0.04$
Ca	$18.40^{a}\pm0.38$	$18.46^{a}\pm0.33$	$17.41^{b}\pm0.48$	$17.87^{b}\pm0.40$	$16.97^{b}\pm0.51$	$18.40^{b}\pm0.58$	$15.73^{a}\pm0.19$	$17.81^{a}\pm0.17$	$14.23^{b}\pm0.35$	$16.73^{b}\pm0.31$
Mg	$13.22^{a}\pm0.11$	$13.96^{a}\pm0.18$	$12.13^{a}\pm0.27$	$13.83^{a}\pm0.21$	$10.23^{a}\pm0.23$	$11.60^{a}\pm0.23$	$9.96^{a}\pm0.46$	$11.08^{a}\pm0.41$	$11.73^{b}\pm0.14$	$12.09^{b}\pm0.24$
K	$7.51^{a}\pm0.26$	$7.84^{a}\pm0.23$	$6.67^{a}\pm0.28$	$6.72^{a}\pm0.21$	$5.80^{b}\pm0.39$	$5.81^{b}\pm0.33$	$4.92^{b}\pm0.13$	$5.07^{b}\pm0.18$	$6.53^{b}\pm0.38$	$6.56^{b}\pm0.30$
Na	$0.62^{a}\pm0.061$	$0.66^{a}\pm0.69$	$0.63^{a}\pm0.057$	$0.65^{a}\pm0.54$	$0.49^{b}\pm0.055$	$0.51^{b}\pm0.65$	$0.36^{c}\pm0.034$	$0.39^{c}\pm0.58$	$0.31^{b}\pm0.051$	$0.34^{b}\pm0.51$

Notes: Different superscripts indicate significant differences (p<0.05) between species in nutrient concentrations. Values are means ± s.d. (n=15), Abbreviations: GL (Green leaves), SL (Senescent leaves). a= p< 0.001, b= p < 0.01, c = p< 0.05.

The species that contributed the highest nutrient concentrations in the soil were *A. nilotica* and *A. leucophloea* (Table 2). Moreover, *A. nilotica* leaves were decomposed relatively rapidly and had higher nutrient concentrations, while *A. leucophloea* and *M. tomentosa* leaves were decomposed more slowly (Palma et al. 1998). The observed differences in the chemical composition of leaves, twigs and reproductive parts of the five species studied may affect the nutrient cycle of the ecosystem since decomposition depends on nutrient concentration and in turn, the flow of bioelements depends on the mineralization of the litter produced (Santa Regina et al. 1997).

Nutrient resorption

The percentages of resorption of bioelements like N, P, Ca, Mg, K, and Na are given in Table 3. Nutrient concentrations in green leaves were higher than those in senescent leaves with lower values of resorption efficiency. N resorption efficiency (NRE) varied from 6.48% (*T. grandis*) to 15.16 % (*B. monosperma*), P resorption efficiency (PRE) varied from 5.13% (*B. monosperma*) to 9.23% (*M. tomentosa*), Ca resorption efficiency (CaRE) varied from –17.57% (*B. monosperma*) to –0.33% (*A. nilotica*), Mg resorption efficiency (MgRE) varied from –14.01% (*A. leucophloea*) to –3.07 % (BM), K resorption efficiency (KRE) varied from –4.39% (*A. nilotica*) to –0.17% (*T. grandis*) and Na resorption efficiency (NaRE) varied from -9.68% (*B. monosperma*) to –3.17% (*A. leucophloea*), (Table 3). The resorption efficiency differs among all tree species. The present findings were similar to that of Del Arco et al. (1991). Bioelements such as Na, Mg, K and Ca were generally strongly resorbed and the index of re-

translocation was varied between species. However, Sodium showed significant resorption in *B. monosperma* (–9.68) and *M. tomentosa* (–8.33), whereas the value was lower in *A. nilotica* (–6.45 %), *T. grandis* (–4.08 %) and *A. leucophloea* (–3.17 %). Ca, Mg and Na resorption efficiency was positively correlated with that of green leaves (Ca, r = 0.97, p <0.01; Mg, r = 0.48, p<0.01 and Na, r = 0.80, p<0.01) whereas N, P and K resorption efficiency was negatively correlated with that of green leaves (N, r = –0.45, p<0.01; P, r = –0.13, p<0.01 and K, r = -0.21, p<0.01).

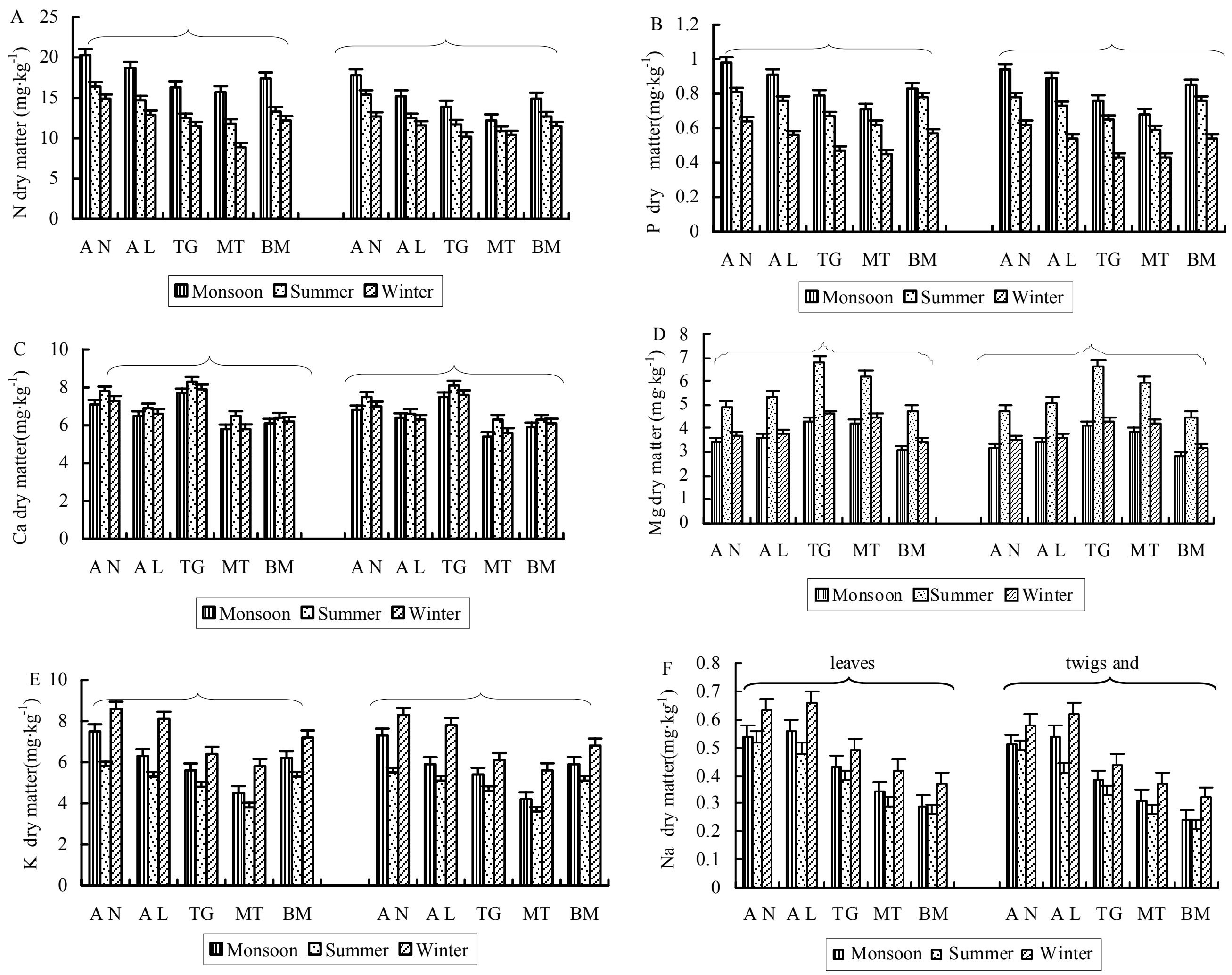

Fig. 1 Nutrient contents in leaves, twigs and reproductive parts of (A) nitrogen, (B) phosphorus, (C) calcium, (D) magnesium, (E) potassium and (F) sodium. Abbreviations: *Acacia nilotica* (AN); *Acacia leucophloea* (AL); *Tectona grandis* (TG); *Miliusa tomentosa* (MT); *Butea monosperma* (BM). Leaves on the left, branches and fruits on the right. Bars indicate S.E. (n =15).

Senescent leaf nutrient concentration affects nutrient resorption efficiency. This would be supported with the results of a study of resorption efficiency in Alaskan birch (*Betula papyrifera* var. *humilis* (Reg.)) in which lower P resorption efficiency was only observed for trees growing in a very fertile lawn (Chapin 1991). The Lajtha (1987) suggested that resorption efficiency could be maximum in plants of intermediate nutrient status, which was also consistent with our results that resorption efficiency increased from high to intermediate leaf nutrient concentration.

Existing evidence suggests that the efficiency of nutrient resorption may be determined primarily either by soil nutrient availability (Ostman et al. 1982) or by plant nutrient status (Negi et al. 1993). The relationships established in our study between nutrient concentrations from senescent leaf and their respective litter nutrient concentrations using the mean nutrient concentrations of all species pooled together. Moreover, only when trees of the same species were grown on different sites, there were differences in nutrient concentrations as well as resorption efficiency from senescent leaf.

Percentage of nutrient retranslocation

The percentages of retranslocation of nutrients N, P, Ca, Mg, K, and Na were varied between species (Table 3). The percentage of bioelements retranslocated from senescent leaves is markedly

higher than that reported for other species elsewhere (Bargaly et al. 1992; Lodhiyal et al. 2002). Retranslocated Na and P may provide most of the demand for these bioelements during consequent year for the formation of new leaves (Del Arco et al. 1991). In relative terms, Na, Mg, K and Ca were accumulated in senescent leaves. The retranslocation of bioelements from the senescent leaves in present study was in order of Mg (49.17–69.74) > Ca (52.86–61.86)>N (10.42–24.80)>P (7.69–18.99)> Na (2.78–12.24) > K (1.05–5.05), (Table 4).

Table 3. Percentage of resorption efficiency of bioelements in leaves of different tree species (%)

Bioelements	*Acacia nilotica*	*Acacia leucophloea*	*Tectona grandis*	*Miliusa tomentosa*	*Butea monosperma*
P	8.08	8.14	8.86	9.23	5.13
Ca	-0.33	-2.64	-8.43	-13.22	-17.57
Mg	-5.60	-14.01	-13.39	-11.24	-3.07
K	-4.39	-0.75	-0.17	-3.05	-0.46
Na	-6.45	-3.17	-4.08	-8.33	-9.68

Note: "-" Indicates nutrient resorption (n =15).

Table 4. Magnitude of retranslocation of bioelements (%) in leaves of different species

Bioelements	*Acacia nilotica*	*Acacia leucophloea*	*Tectona grandis*	*Miliusa tomentosa*	*Butea monosperma*
N	10.42	16.28	22.95	24.80	23.59
P	18.18	13.95	18.99	9.23	7.69
Ca	59.78	61.52	52.86	61.86	56.43
Mg	69.74	65.38	49.17	49.80	68.46
K	2.80	1.05	3.5	4.47	5.05
Na	9.68	9.52	12.24	2.78	3.23

Conclusions

The results confirm that the bioelement analysis of senescent leaves or litter can be used to evaluate the nutritional status of all five tree species. With regard to bioelements N, P, Ca, Mg, K and Na, the analysis of senescent leaves cannot substitute for that of fresh leaves in all species. A marked seasonal variability was observed in the concentrations of N, P, K and Na with no or less important differences for Ca and Mg. These variations in nutrient concentrations were greater in leaves than in branches and fruits. Overall, the leaves played the major role in nutrient recirculation. From the present study, it may be revealed that N, P, K and Na displayed the greatest seasonality, possibly because they were the most mobile elements (Helmisaari 1992), whereas those with lower mobility (such as Ca and Mg) did not change during the year. Bioelements such as Na, Mg, K and Ca were strongly resorped and retranslocated.

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